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R. A. Hartenberger

Teledyne Geotech

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SEISMIC DATA ANALYSIS CENTER QUARTERLY TECHNICAL SUMMARY REPORT
JANUARY - MARCH 1975

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15 April 1975

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ABSTRACT

This report summarizes the scientific work accomplished at the Seismic Data Analysis Center (SDAC) in the interval January through March 1975.

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AVERAGE P AND PKP CODAS FOR EARTHQUAKES (103°-118°) (TR-73-10)

The coda analyses presented in this report complement our previous studies of P and PKP codas for earthquakes (Cohen et al., 1972; Sweetser et al., 1973), and specifically detail coda characteristics in the distance interval 103 to 118°. Earlier studies performed using seismograms recorded at a network of Worldwide Standard Seismograph Stations (WWSSS) did not adequately define coda characteristics in this interval, especially for small events (NOS $m_b \leq 5.8$) recorded at distances where P_{diff} is the first arrival. Because coda determinations are often used to determine how often signals from one event are masked in the coda of another event, it is necessary to have a complete set of coda observations with which to predict coda for a specified event.

In this study we analyzed seismograms of 26 small events ($m_b \leq 5.8$) recorded at a world-wide network of 10 stations, and of 26 large events (m_b, M_s, or secondary $m_b \geq 7.0$) recorded at a world-wide network of 16 stations, to produce estimates of the coda decay characteristics for events in the distance interval 103-118°. As a result of the study, we conclude that for times greater than the arrival time for the PP phase, large event codas are about 0.11 m_b units greater than small event codas at corresponding times into the codas. This supports the hypothesis that large events are multiple events, and the period of source activity is estimated to be 1 to 2 minutes. Two sets of average coda decay curves, one each for large and small events, are given in the original report for the following distance intervals: 103-105°, 105-110°, 110-115°, and 115-118°.

SEISMIC THRESHOLD DETERMINATIONS (TR-74-3)

In this report we discuss the determination of seismic threshold for a station or network of stations which serves to evaluate that station or network in the context of seismic detection. Threshold level reflects several different aspects of the station or network; seismic background noise, relative signal strength, seismometry, recording equipment, processing techniques, and analysis procedures. If one aspires to quantify these effects or to evaluate station and network detection capability, it is then necessary to make an accurate determination of threshold. It is also desirable to have a technique for predicting thresholds and for comparing predictions to observations.

Determining seismic thresholds has several facets in practice. An empirical threshold can be determined directly by plotting the percentage of events detected in each equal magnitude increment against the known magnitudes. This is the direct method; it gives an unbiased threshold only if one has an independent source of magnitude information whose threshold is much lower than the station or network under consideration and whose reported magnitudes have a small variance and are insignificantly biased. Since an independent source of such nature is often unavailable, one must use a method dependent upon magnitude information from the network or station under consideration; this involves plotting the number of events having a certain phase (e.g., LR) detected against the magnitudes calculated from that phase (e.g., M_s). This is the incremental method; thresholds are found by estimating the true seismicity-magnitude relation from the asymptotic part of the data at high magnitudes or by a maximum-likelihood method (Kelley and Lacoss, 1969). We will show that the use of observed, rather than true or independent, magnitudes distorts the simple picture presented by the direct method and effects the threshold determination. A variation of the incremental method is to plot the cumulative number of detections (with magnitude greater than or equal to a given observed magnitude) against the observed magnitudes; this is the cumulative method. We will show that this approach, taken to smooth the data points, heightens the threshold distortion even more.

Another somewhat different approach is used in seismology and is a type of direct threshold determination. Here, in the manner of the direct method, the percentage of detections of surface waves in a given body-wave magnitude increment is plotted against the body-wave magnitude, supplied by a source which presumably detects body waves much more frequently than the station or network under consideration detects surface waves. Thresholds are then converted from the m_b to M_s scale. We will show how this method of M_s threshold determination is so fraught with pitfalls that only the most careful attention to detail can produce reliable thresholds.

The matter of calculated thresholds, by use of the program NETWORTH (Wirth, 1970), also deserves attention since the authors have noted cases of inacceptable discrepancy between calculated and observed thresholds. All the discrepancy is not necessarily due to faulty empirical threshold determination, and we must reconsider the assumptions in the common scheme for calculating station or network thresholds.

This report discusses several of the important aspects of threshold determination, calculated and observed, which we feel have not been given exposure or properly interrelated; we feel that attention to these aspects, along with those presented by previous investigators, will result in unbiased threshold determinations which are suitable for use in comparisons between stations and between networks.

We must make some simplifying assumptions about certain phenomena in order to make the mathematics tractable; they are, however, realistic and commonly used. Therefore, we allow the signal amplitudes from an event to be lognormally distributed (Freedman, 1967; von Seggern, 1972). The same applies to the noise amplitudes at a station (Geotech, 1966). We allow the logarithm of the number of events which occur in a specified time interval to be proportional to magnitude (Gutenberg and Richter, 1954; Scholz, 1968); that is, we use a linear seismicity-amplitude relation throughout. We also assume a linear relationship between M_s and m_b everywhere.

The first parts of this report establish the concepts, and theoretical derivations are given when necessary. A later part of this report describes the method and results of a simulation experiment which serves to verify the predictions of the first parts and to give insights where mathematical predictions are not attainable. The techniques used in this simulation are essential tools for satisfactory evaluations of practical networks. The last part of the report deals with refinements in calculating seismic thresholds.

We conclude that many of our problems in threshold determination can be handled analytically. We established in this manner that:

1. For a single station, the 50% incremental threshold magnitude using observed magnitudes is the same as the 50% direct threshold determination using operational magnitudes; but the 90% and 10% are lower and higher, respectively.

2. The single-station incremental curve on observed $\hat{m}$ smoothly dies off, but the network curve has a hump near the threshold.

3. The seismicity-magnitude relation determined using observed magnitude will always be displaced upward in magnitude compared to the true seismicity.

4. Cumulative threshold magnitudes, either network or single-station, will always be lower than the incremental ones.

5. The distribution of magnitudes along a straight line (horizontal or vertical) through a population of M_s-m_b data is dependent on the seismicity magnitude relation and, although normal, has varying parameters.

We further conclude that simulation results agreed with theoretical predictions wherever comparison was possible. The simulation experiment established these important facts:

1. Varying the P threshold does not affect the single station direct LR threshold on $\hat{m}_b$ but does affect the network threshold. Incremental and cumulative thresholds can be strongly affected in either case.

2. The hump in the network LR incremental detection curve is reduced by assuming significant source bias and also by plotting versus $\hat{m}_b$ rather than $\hat{M}_s$.

3. The 90% single-station LR thresholds in terms of $\hat{m}_b$ are typically much greater than the thresholds in terms of $\hat{M}_s$ (assuming $M_s = m_b$) on the order of 0.4 magnitude units. In general, really substantial effects are possible and care must be exercised when comparing thresholds determined in different ways.

4. Noise correlated between stations at realistic levels ($\rho=0.4$) has an almost negligible effect on thresholds in the presence of realistic levels of source bias.

5. The seismicity bias for large magnitudes is negligible if network magnitudes are used, except in the presence of source bias in which case it may be on the order of 0.1 magnitude unit.

6. For realistic network parameters, compared to the 1/10 thresholds, the 2/10 thresholds increase by 0.10-0.15 magnitude unit and, compared to the 2/10 thresholds, the 4/10 thresholds increase by a similar amount. This is in rough agreement with, but slightly less than, the NETWORTH differentials of 0.15-0.20.

7. Use of the error function as a probability of detection curve for a network can in some cases be a poor approximation to the curve deduced by simulation.

8. The true M_s-m_b relationship is accurately estimated by the maximum likelihood method if a suitable low cutoff is made on the M_s and m_b values. Regression of m_b on M_s also yields accurate results if that 10% of the events with the lowest M_s values are excluded from the calculation.

As an example of the usefulness of the simulation approach to threshold problems, good agreement was achieved between simulated results from MSBNET and LASA data for LR and P detection.

Finally, in regard to predicting seismic thresholds, we emphasize the importance of determining realistic background "noise" values which take into account seismic waves from known sources and also the importance of determining the S/N ratio required for detection in a specified context.

THE EFFECTS OF REDUCED CONFIGURATIONS AT LASA ON DETECTION SIGNAL-TO-NOISE RATIOS (TR-74-7)

A series of off-line Detection Processor (DP) experiments were performed on data from the Large Aperture Seismic Array (LASA) in Montana to determine the effects that the number of subarrays and number of sensors per subarray have on the output of the computerized seismic analysis system at the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. The outputs of the system are the seismic events listed in a Daily Summary, the DP detections, etc. (See Dean et al., 1971, for a complete discussion of the SDAC/LASA system).

The functional flow of data from LASA through the SDAC/LASA system is: 1) data acquisition; 2) detection processing; 3) event processing; 4) experimental operations console (EOC) editing; and 5) publishing of the Daily Summary. The experiments discussed in this report concern themselves only with function 2), detection processing, and the resultant signal-to-noise ratios of the detected signals. The detection parameters used are those discussed by Chang (1974) using LASA Beam Set 133 in Partition I and LASA Beam Set 140 in Partition II.

Earlier studies of the effects of reducing the number of elements at LASA (Hartenberger, 1967; Hartenberger and Van Nostrand, 1970) have shown that the signal-to-noise ratio loss is less than 2db compared to that for the original 525 sensor array when the number of elements is reduced to 119 or 51 with minimum sensor spacing of 3km or 6km respectively. All of the data used in the earlier studies were prefiltered (0.4-3.0 Hz), were beamed to the known epicentral locations, and were corrected for travel-time anomalies (Chiburis, 1968). Also, the event set contained only earthquakes well above magnitude 4.7.

Such differences (between the present study and these earlier ones) as filter pass-band (0.9-1.4 Hz here) travel-time residuals, and subarray and array beam deployment may adversely affect an accurate comparison between them. The comparisons of relative S/N improvement between experiments in this paper should, however, be valid, since these parameters are held constant between experiments. Care must be taken, however, that non-detection of weak events by small subsets of the full LASA does not lead to biased estimates of the (S/N) loss. The experiments performed in this report simulate the on-line processing of a continuous data stream and include events near the detection threshold of the array (m_b = 3.7-4.0).

The results obtained from the present study, in which several experiments were performed on LASA data with reduced array configurations, lead to the following conclusions:

1. The detection signal-to-noise ratio for a 16 element subarray D-ring size LASA is within 0.2±0.3db of that for an E-ring sized LASA.

2. Further reducing the array to an aperture of the C-ring produces losses of 2.3±0.3db.

3. Eliminating, within a subarray, the six sensors nearest the center produces less than one db of loss in the detection signal-to-noise ratio.

The foregoing conclusions are based on the assumption that each subarray is beamed before the entire array is beamed. If infinite-velocity subarray beams are formed, the results can be expected to differ from those in this report. The effects of infinite-velocity subarray beams, and number of sensors per subarray, are currently under investigation.

ANALYSIS OF SEISMIC DATA OF THE RIO BLANCO EXPLOSION (TR-74-9)

In this report we examine several seismic aspects of the RIO BLANCO shot, including location, magnitude, source function, and shear-wave generation. Comparisons are made with RULISON and with nuclear explosions and earthquakes in the western United States in general. The report on RULISON by Lambert and Ahner (1972) is the basic reference for this report.

RIO BLANCO was the third of a series of gas-stimulation nuclear explosions in the PLOWSHARE program. Basic site information on this shot is given in the report. The feature of interest was the multiple nature of the shot--actually three simultaneous and closely spaced detonations. A previous gas stimulation shot, RULISON, was located 55.9 km to the southeast of the RIO BLANCO should help to elucidate what, if any, effects the multiple detonation had on seismic signals.

In summary we note that data from only a few North American sites and the NORSAR array were sufficient to locate and roughly characterize the RIO BLANCO event. In spite of the multiplicity of the detonation, RIO BLANCO signals did not differ in any apparent manner from ordinary explosions, with RULISON as the main comparative measure. Through homomorphic filtering, inverse filtering, and cepstral analysis, we were able to see the pP reflection and possibly the spall impact. No direct shear waves were identified for RIO BLANCO and Love wave generation was less than that of typical NTS shots. Spectral content of P signals for RIO BLANCO was similar to RULISON, and LR signals were visually similar at stations common to both events.

AN EXAMINATION OF SOME NEW AND CLASSICAL SHORT-PERIOD DISCRIMINANTS (TR-74-10)

Optimum linear and quadratic discrimination filtering techniques are developed in this report for discriminating between short period seismic records originating from earthquakes and explosions. Linear and quadratic detection filtering and matched filtering are compared with the classical spectral ratio and complexity measure using a learning population of LASA array beams of 23 earthquakes and 15 explosions and a test population with 17 earthquakes and 11 explosions. The results of this study show that the linear detection filter misclassifies one event in the test set whereas all other techniques misclassify between three and five events.

We also show that for the spectral ratio discriminant the discriminatory power lies in the ratio of .4-.8 Hz energy to 1.0 Hz energy, and that the higher frequency energy has no additional discriminatory power. We find that the explosions which fail to discriminate were probably cratering experiments. In either this case, or if the explosion is deep, pP will not cancel P at low frequencies. Thus, we propose that pP-P cancellation is the basic physical explanation for the success of short period discrimination.

SEISMIC THRESHOLD DETERMINATION

D. H. von Seggern

To be presented orally at the Seismological Society of America Annual Meeting
March 25-27, 1975

The SDAC has been involved both in predicting seismic magnitude thresholds for seismic stations and networks and in determining empirical thresholds for them for a number of years. We were always aware that certain biases arose in simple empirical estimations of such thresholds since these observed thresholds often deviated significantly from predicted ones, but only recently have we considered in detail the full range of subtleties which cause these discrepancies. These subtleties involve interactions of seismic event recurrence curves, M_s versus m_b relationships, both variance and correlation of signal and noise amplitudes, and the threshold probabilities themselves. Some of our insights into threshold determination have resulted from analytic derivations, but the most practical results pertaining to networks with varying signal and noise levels came through computer simulations of typical observed data sets.

AN ITERATIVE APPROXIMATION TO THE MIXED-SIGNAL PROCESSOR

R. Blandford, T. Cohen, and J. Woods

To be published in the Geophysical Journal

An iterative array processor for two simultaneously arriving signals is developed which gives estimates equal to the maximum likelihood estimates. Using this processor, the array is first beamed on one of the two events to produce a signal estimate which is then time-shifted and subtracted from each of the original traces. The difference traces are then beamed to produce a signal estimate for the second event. The estimate for the second event is now shifted and subtracted from the original traces, and the resulting difference traces are rebeamed on the first event. The process is repeated until differences in successive signal estimates for the desired event fall below a predetermined threshold. In addition to its use in processing two simultaneously arriving signals, the processor can be of use for detection of secondary phases in the coda of an event.